TABLE 3.—*Tests of 2 Friez magneto anemometers equipped with standard 3-cup wheels. Run 64, magneto built without wind vane; run 65, another magneto with wind vane; run 66, same magneto with vane removed. Indicated velocities read from voltmeter scale graduated directly in miles per hour*—Continued

Date and run	Observed data. Velocity m/hr.		Derived data		Specifications
	Wind, W''	Voltmeter velocity V	Cup turns per mile, $N=\frac{640V}{W_{\prime}}$ approximate	Factor $W \div v$ $F=\frac{10084}{LN}$	
1929 June 7, No. 65.	12.6	12.7	646	2.50	Standard 3-cup wheel:
	19.2	20.0	667	2.42	Similar magneto, but equipped with wind vane.
	24.9	25.0	643	2.51	
	31.1	32.3	665	2.43	d=5.03 inches.
	35.5	38.3	690	2.34	L=6.244 inches.
	42.8	45.4	679	2.38	P=2.5 meters.
	45.7	50.0	700	2.31	Large tunnel, open air.
	52.4	56.8	694	2.31	
	56.8	63.5	715	2.26	
	57.8	64.0	720	2.24	
	64.6	71.5	708	2.28	
	69.6	77.0	708	2.28	
	59.0	65.3	708	2.28	
	46.5	50.7	698	2.31	
	31.9	33.4	670	2.41	
	20.3	20.3	631	2.56	
June 7, No. 66.	14.1	13.0	590	2.74	Same cup wheel and magneto, with vane removed, necessitating an improvised substitute for ball bearing. Large tunnel, open air.
	21.8	21.4	628	2.57	
	26.0	26.7	657	2.49	
	31.7	33.2	670	2.41	
	39.2	41.5	678	2.38	
	46.3	50.4	697	2.32	
	49.2	54.3	706	2.29	
	55.9	61.5	704	2.29	
	60.5	66.5	703	2.30	
	65.4	72.2	707	2.28	
	70.6	78.3	710	2.27	

TABLE 4.—*Data and constants for hyperbolic equations, asymptotes parallel to coordinate axes, giving the relations between N, number of turns per mile of wind velocity, and W, the wind velocity in meters per second*

EQUATION, $N=\frac{b(W-W_o)}{W+a}$

Case	Cup wheel			Max. $N\ b$	Curvature a	Friction W_o	Remarks
	No.	Arms L	Cups diameter, d				
		Inches	*Inches*				
1	18	2.34	4.0	1,650.0	−0.113	0.30	Shortest arms for 4-inch cups.
2	34	3.81	4.5	1,100.0	.002	.67	Two 1/1000-mile wheels tested on Friez no vane magneto.
	35	3.92	5.0				
3	19	4.78	4.0	922.5	.847	.30	Duplicate wheels; 2 runs.
	20	4.78	4.0				
4	28	5.14	5.0	893.1	1.064	.30	Single run on 1 wheel.
5	31	5.24	6.0	835.2	.548	.30	Do.
6	21	5.33	4.0	834.5	1.040	.30	Do.
7	25	5.40	4.5	857.7	1.013	.30	Do.
8	---	6.25	5.02	745.4	.909	.67	2 standard 3-cup wheels tested on 2 Friez magnetos.
	---	6.24	5.03				
9	30	6.29	5.0	696.6	.919	.30	Only 3-cup wheel close to standard tested in tunnel, velocity range 7 to 35 m/sec.
10	26	6.55	4.5	704.8	1.030	.30	3-cup wheel, thick arms; 3-cup wheel arms thinner.
	26	6.55	4.5				
11	32	6.56	6.0	711.6	.841	.30	Nos. 8, 9, 10, 11 nearly like 3-cup standard.
12	----	6.677	4.0	686.4	1.313	.30	Mean of 68 tests on aluminum 4-cup wheels over maximum range of velocity 4–61, m/sec.
13	----	6.677	4.0	678.2	1.582	.30	Mean of 33 tests to highest velocity of copper 4-cup wheels.
14	33	8.56	6.11	530.1	.093	.50	Heavy brass cup, long arms.
15	22	8.59	4.0	551.0	1.527	.30	2 long arm cup wheels.
	27	8.59	4.5				

NOTE.—Nos. 12 and 13 in this table relate to the large number of tests on the 4-cup anemometers. A few of these tests were carried to the extreme velocity of 60 meters per second. All the remaining cases represent often only a single run on 3-cup wheels, and of these only 8, 9, 10, and 11 represent anemometers which are fairly comparable, not identical, with the present 3-cup standard. Only in case 3, duplicate cup wheels 19 and 20, did the velocity exceed 35 meters per second, and in this case the cups were deformed above 40 meters per second, leaving the performance of the 3-cup wheels at high velocities in doubt.

WET-BULB DEPRESSION AS A CRITERION OF FOREST-FIRE HAZARD

By J. R. LLOYD

[Weather Bureau, Chicago, Ill., March 10, 1932]

Ever since the inauguration of the fire-weather work by the Weather Bureau in the forested areas of this country there has been a need for a convenient scale or formula for use in estimating the combined effects of temperature and relative humidity on forest-fire hazard. It has been known for a long time that both temperature and relative humidity exert an influence on fire hazard. However, these two elements are so associated that it is very difficult to assign proper values to each. The writer has for several years been engaged on fire-weather work in the upper Great Lakes region, and therefore has more than an ordinary interest in this problem. If a single scale or formula could be found that would measure the combined effects of temperature and relative humidity on forest-fire hazard to a reasonable degree of accuracy it would go a long way in solving one of the most difficult problems in fire-weather work.

In order to start on this problem it was necessary to gather a lot of data on forest fires. The writer chose the season of 1930 for fire data because of the fact that most of the season was bad from a hazard standpoint. Fire report cards were sent to the district forest rangers, who reported on about 5,000 separate fires that occurred in Wisconsin and Michigan during 1930. One report card was used for each fire, on which was shown the time of beginning and of ending of the fire, the area burned, the type of forest cover burned, and the kind of soil, in general, that was burned over. With this information at hand and with the weather data that had been collected from several fire-weather stations in the forested area, it was possible to attack the problem from several angles, if necessary.

It was decided to chart each fire against the temperature and relative humidity that prevailed at the time the fire broke out. The accompanying chart, Figure 1, shows the manner in which this was done, except the chart as originally prepared showed in colors the sizes of the fires according to several different size classifications, which can not be shown on the chart herewith. Only the fire reports from the districts that had weather observing stations and reliable records were used. By way of explanation of the chart, it should be said that each dot represents a fire, and that the position of each dot on the chart indicates the temperature and the relative humidity that prevailed shortly before the fire was first noticed by the forest guard. It should be noted that each degree of temperature is represented by a band 5 millimeters wide running vertically on the chart, and each 1 per cent of relative humidity by a 5 millimeter band running horizontally across the chart. The fires are charted in the 5-millimeter squares at the intersections of these bands that represent temperature and relative humidity. It may be seen that in some of the 5-millimeter squares as many as eight fires have been charted. A total of 3,002 fires were charted.

When the chart is examined carefully it will be found that it presents some very interesting features. Probably the most outstanding feature is the heavy preponderance of fires that broke out with temperature above 70° and relative humidity below 45 per cent. This indicates that the greatest danger of fire inception lies in that sector of the chart. Part of this heavy preponderance is, no doubt, due to the fact that more chances occur for fires to break out during the run of a season with temperatures between 70° and 90° and relative humidity between 45 per cent and 25 per cent than at other temperatures and humidities, because those temperatures and humidities probably occur more frequently during the fire season than do other temperatures and humidities. It would be extremely difficult, in fact impossible, considering the manner in which the fires are charted, to show just how much more chance there is for fires to break out under the former named conditions than under the latter. However, it is known from experience in dealing with the problem from day to day that only a part of the preponderance as shown on the chart is caused by more frequent occurrence of weather conditions in that sector of the chart that would cause fires, and that probably only a rather small part of the preponderance is due to that feature.

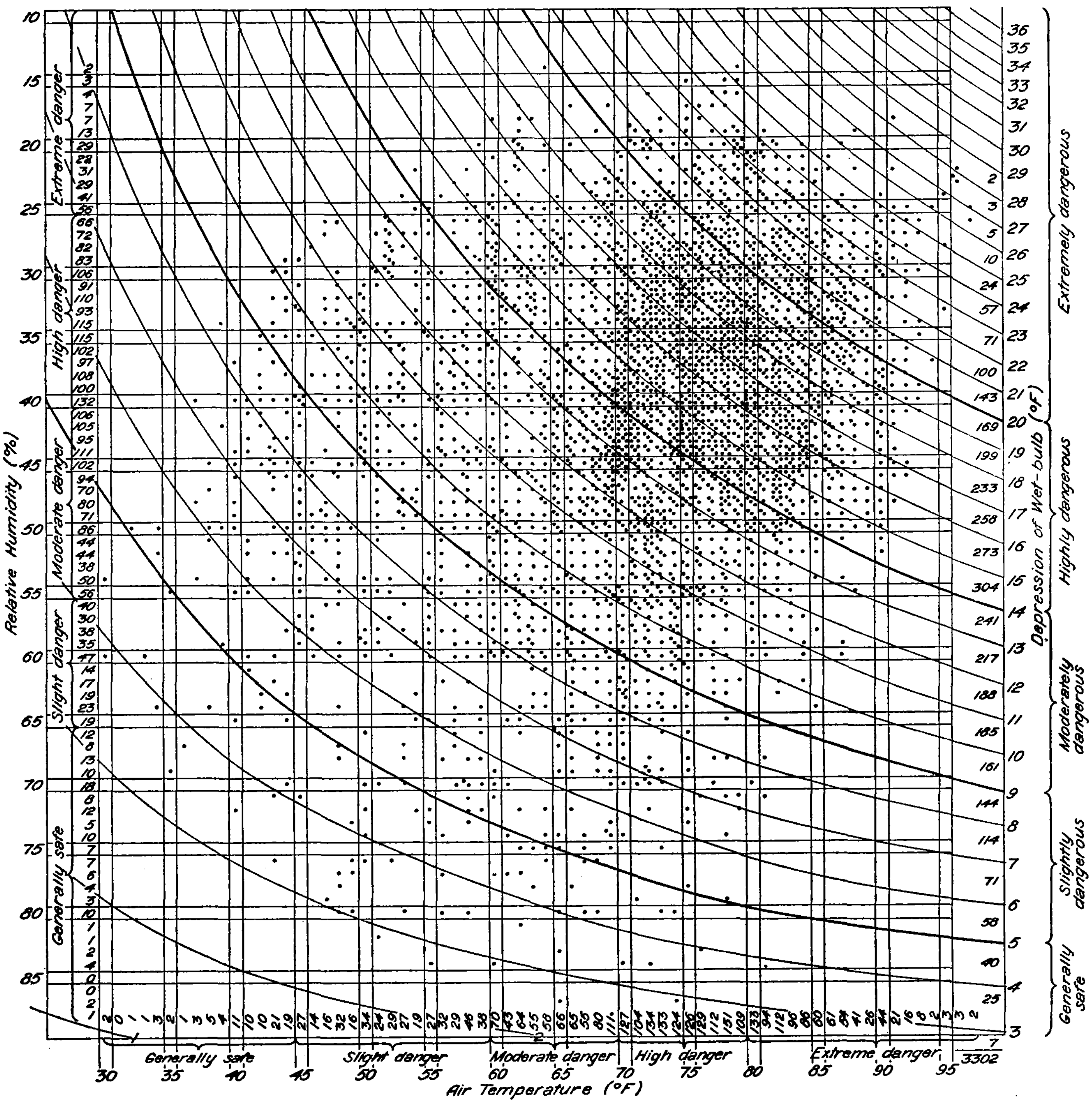

FIGURE 1

As the principal reason for charting the fires in the manner shown was to determine some method of estimating accurately to a reasonable degree the combined effects of temperature and relative humidity on fire hazard, it appeared that the wet-bulb depression might prove to be the most satisfactory agent. Accordingly, the wet-bulb depression values were computed for the various combinations of temperature and relative humidity, and lines for each whole degree variation in depression were drawn on the chart. It was immediately apparent that wet-bulb depression combines the evaporating qualities of both relative humidity and temperature in such a manner as to give assurance that it would be a very satisfactory gage for hazard of fire inception. It might be well here to caution the reader not to confuse hazard of fire inception with fire hazard in its entire scope. The two are often very different, for in the larger scope wind velocity is extremely important, and several other factors also enter into the problem. This paper treats chiefly on hazard of fire inception.

Near the right-hand margin of the chart, in small figures, is entered the number of fires that occurred for each 1° gain in wet-bulb depression. It may be seen that the number of fires increases steadily with each degree gain in depression up to 15°, and then the number gradually decreases. However, this does not mean that the fire hazard decreases as the wet-bulb depression increases above 15°, for it actually increases as long as the wet-bulb depression increases. That the peak number of fires is reached between depressions of 14° and 15° is due largely to the fact that more chances occur for fires to break out at that depression than at greater depressions, because the greater depressions occur less frequently. In other words, if wet-bulb depressions of 25° were as frequent in occurrence as depressions of 15° it would be reasonable to expect that the number of fires breaking out for each 1° gain in depression would gradually increase between depressions of 15° and 25°, and that the peak number of fires would be at 25° instead of 15°.

Since it was established that there was a gradual increase in hazard of fire inception with an increase in wet-bulb depression, it was then desirable to determine zones of hazard on the wet-bulb depression scale. These zones were determined by inspection of the chart, by knowledge gained from experience, and from the hazard zones laid off on the relative humidity and temperature scales, which were entered first. The hazard zones on the humidity and temperature scales were determined by inspection of the chart, by actual experience, and from the results of studies made by certain fire-weather investigators in the United States Forest Service. They are laid off to represent near normal conditions that prevail in the Lake States, as are also the hazard zones on the wet-bulb depression scale. During long periods of drought the humidity zones would have to be shifted downward somewhat, graphically speaking, as would also the wet-bulb depression zones. It should be noted that the hazard zones on the depression scale are laid off so that they bear a direct relationship to the zones on the humidity and temperature scales. For instance, the lines separating the generally safe and the slight danger zones on the humidity and temperature scales intersect on the heavy line that divides the generally safe and slightly dangerous zones on the depression scale. Likewise the dividing lines between the slight and moderate danger zones and the moderate and high danger zones on the humidity and temperature scales intersect on or near the dividing lines between the slight and moderate danger zones and the moderate and high danger zones on the depression scale. The heavy line dividing the high and extreme danger zones on the depression scale was moved down a degree from the intersection point of the dividing lines for the same temperature and humidity zones, because it was felt that in this case the intersection point fell a little too high on the scale.

It is obvious from the chart that there is no fire hazard with a wet-bulb depression of less than 3°, and very little hazard below a depression of 5°. From 5° to 9° there is slight danger; from 9° to 14° the danger is usually moderate; from 14° to 20° the danger is high; and that above a depression of 20° extreme danger usually prevails. It should be noted that the wet-bulb depression lines curve in such manner as to give, in large measure, about the same weight to temperature in determining hazard as is given to relative humidity. One would expect this to be true when it is realized that wet-bulb depression is a good index of evaporation; and since evaporation and fire hazard are linked very closely together, especially in sections of the country where periods of rainy weather are usually frequent. The importance of wet-bulb depression on evaporation is shown by a statement by Humphreys [1] to the effect that—

> Many observations have shown that, to at least a first approximation, the rate of evaporation is directly proportional, other things being equal, to the difference in temperature indicated by the wet and dry bulb thermometers of a whirled psychrometer.

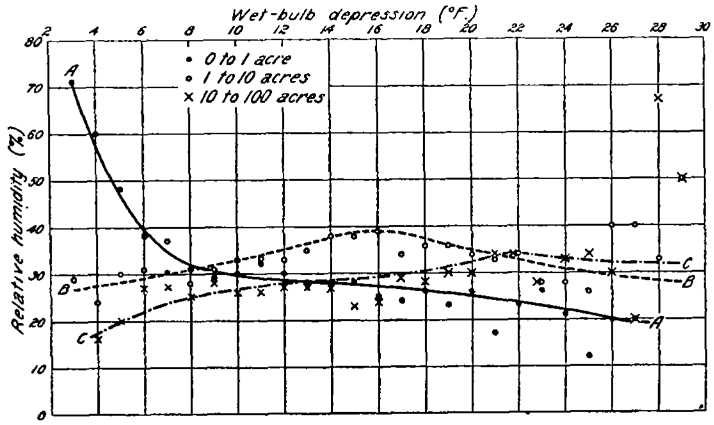

FIGURE 2

Of course in actual practice it is not possible to have "other conditions equal" so far as forest fuels are concerned. There is usually more or less air movement, and in the daytime sunshine is very important as a factor in evaporation. Both of these factors must be considered in the estimation of fire hazard. However, of the two, the former is of the least importance in hazard of fire inception, for the air that comes in contact with the forest fuels on the ground has little movement, as a rule. However, after a fire is once ignited wind movement in most cases plays the most important rôle of all the weather factors.

As mentioned in the foregoing discussion, the original chart showed the sizes of the fires according to several size classifications. In order to show how the size of the fires varied according to each 1° change in wet-bulb depression a tabulation was made as shown in Table 1. In this tabulation the number of fires that occurred at each degree of depression is shown for each size classification, and the per cent that each number is of the total number of fires for each degree in depression is also given. These percentages are interesting. The figures on the class A

[1] W. J. Humphreys, Physics of the Air, p. 247.

fires show that the percentages decrease from the beginning as the wet-bulb depression rises. This is exactly what would be expected. With the class B fires the percentages rise gradually as the depression rises until a depression of 16° is reached, and then there is a gradual decline, except at depressions above 25°, where the number of fires is too few to give reliable percentages. Under class C the percentages gradually increase until a depression of 21° is reached, and then there is a slight decline, disregarding the last two figures. With class D fires the peak is reached at a depression of 23°. Under class E and class F the number of fires that occurred was really too small relatively to give reliable percentages; however, the figures given indicate that the highest percentages in these two classes were reached at a depression of about 25°. The interesting feature is that the peak on the percentage scale of each class of fires falls at a higher point on the wet-bulb depression scale as the size classifications increase. This indicates that, regardless of wind velocity, which is the big factor in fire spread, fires increase in size as the wet-bulb depression increases. The percentage figures on fires under classes A, B, and C, as shown in Table 1, are presented in graphic form in Figure 2. In Figure 2 the curves drawn for the A, B, and C fires are smoothed out to take care of the inconsistencies shown in the table. A tabulation of let us say 10,000 fires would undoubtedly smooth out the percentage curves so that they would probably appear about like the smoothed curves shown in Figure 2.

It is believed that use of the wet-bulb depression as a criterion of forest fire hazard is a real step forward in fire-weather work. The idea was given a trial during the season of 1931 and found to work very satisfactorily. In the Lake States district an effort is made to predict the maximum temperature and the minimum relative humidity for the ensuing day. Therefore a chart such as the one shown here should be valuable aid to the forest ranger as well as to the meteorologist, for it enables one to assign about the proper weight to both the temperature and the relative humidity that is expected, or that may be prevailing, in estimating the hazard. In working out the wet-bulb depression idea other methods for determining the combined effects of temperature and relative humidity on fire hazard were tried and eliminated, either because they were not of much value or because they were impractical for daily use.

TABLE 1

Wet-bulb depression	A 0 to 1 acre		B 2 to 10 acres		C 11 to 100 acres		D 101 to 500 acres		E 501 to 1,000 acres		F 1,000 acres and over		Total number of fires
	Fires	*Per cent*	*Fires*	*Per cent*	*Fires*	*Per cent*	*Fires*	*Per cent*	*Fires*	*Per cent*	*Fires*	*Per cent*	
3	5	71	2	29	0	0	0	0	0	0	0	0	7
4	15	60	6	24	4	16	0	0	0	0	0	0	25
5	19	48	12	30	8	20	1	2	0	0	0	0	40
6	22	38	18	31	16	27	1	2	1	2	0	0	58
7	21	30	26	37	19	27	3	4	1	1	1	1	71
8	37	31	32	28	28	25	11	10	3	3	3	3	114
9	42	29	44	31	40	28	13	9	2	1	3	2	144
10	48	30	53	33	42	26	14	9	2	1	2	1	161
11	60	32	61	33	48	26	12	7	2	1	2	1	185
12	57	30	63	33	50	27	13	7	4	2	1	1	188
13	60	28	76	35	58	27	16	7	5	2	2	1	217
14	68	28	91	38	64	27	10	4	2	1	6	2	241
15	85	28	117	38	70	23	18	6	6	2	8	3	304
16	68	25	106	39	67	24	20	7	5	2	7	3	273
17	61	24	87	34	75	29	24	9	5	2	6	2	258
18	60	26	84	36	65	28	15	6	4	2	5	2	233
19	46	23	72	36	59	30	13	7	4	2	5	2	199
20	43	26	58	34	51	30	13	8	2	1	2	1	169
21	25	17	47	33	49	34	11	8	6	4	5	4	143
22	23	23	34	34	34	34	5	5	2	2	2	2	100
23	18	26	20	28	20	28	11	16	1	1	1	1	71
24	12	21	16	28	19	33	6	10	2	4	2	4	57
25	3	12	6	26	8	34	3	12	1	4	3	12	24
26	2	20	4	40	3	30	1	10	0	0	0	0	10
27	1	20	2	40	1	20	1	20	0	0	0	0	5
28	0	0	1	33	2	67	0	0	0	0	0	0	3
29	0	0	1	50	1	50	0	0	0	0	0	0	2
Total fires	901	-----	1,139	-----	901	-----	235	-----	60	-----	66	-----	3,302

A. WAGNER'S "CLIMATOLOGIE DER FREIEN ATMOSPHÄRE"

Abstract by J. C. BALLARD

This work, which is Volume I, Part F, of the new Handbuch der Klimatologie, contains a systematic treatment of a large amount of widely scattered upper-air observations. Wherever possible, temperature, humidity, pressure and wind conditions with respect to latitude, longitude, and topographical features have been summarized and discussed. Practically no references to clouds have been made.

A large section of the book deals with North America. This is subdivided as follows: (a) Temperatures found with the aid of kites, captive and limited-height sounding balloons, and airplanes; (b) Sounding balloon flights; (c) Relative humidity; (d) Pressure; (e) Wind.

The part dealing with temperatures contains tables of normals based on the latest available data for the standard levels up to 4 kilometers for Ellendale, N. Dak., Drexel, Nebr., Royal Center, Ind., Washington, D. C., Broken Arrow, Okla., Due West, S. C., and Groesbeck, Tex. Other tables show the free-air temperature distribution with latitude and longitude, vertical temperature gradients, and annual amplitudes. The discussion here, as throughout the book, is concise and confined to the most important features.

Although the sounding balloon data were relatively meager, comparison was made between the St. Louis-Omaha region and the Toronto-Woodstock region. The data from the series of sounding balloon observations made during the winter of 1927–28 at 12 Weather Bureau stations were published too late to be included in this part, but a few notes have been added at the end of the book with regard to these data.

Smoothed means of the annual march of the relative humidity for altitudes up to 3 and 4 kilometers are given for the seven stations mentioned above.

Mean barometric pressures for various elevations for several stations are given and also a table of pressure gradients for longitude 97° W.

The section on wind contains tables dealing with air displacement, annual march of the wind velocity and direction, and maps showing mean stream lines for the 1, 2, and 3 kilometer levels. In the discussion of these tables important facts are brought out concerning the effect of the Rocky Mountains on the air displacement.

The second section, dealing with Europe, follows a plan of treatment similar to that for North America. Several tables showing temperatures are given, as well as the average temperature and height of the tropopause for several European stations. The sections on relative humidity and barometric pressure however, are not so well provided with data. Mean pressures, for each season and for the year are given for heights up to 16 kilometers for three stations, viz., Lindenberg, München, and Pavia. Considerable wind data are given for regions north of the Alps.

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